Report for 2001IA1021G: Complementary Investigations for Implementation of Remote, Non-Contact Measurements of Streamflow in Riverine Environment

- Other Publications:
    - C. Polatel (2003). "Signature of Bed Characteristics on Free Surface Velocity in Open Channel Flows," Paper submitted for the Student Competition of the International Association for Hydraulic Engineering and Research (IAHR), Thessaloniky (Greece)

Report Follows:

COMPLEMENTARY INVESTIGATIONS FOR IMPLEMENTATION OF REMOTE, NON-CONTACT MEASUREMENTS OF STREAMFLOW IN RIVERINE ENVIRONMENT

Submitted to

Iowa Sate Water Resources Research Institute
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1. SUMMARY OF CONDUCTED EXPERIMENTS

1.1. FACILITIES AND INSTRUMENTATION

The set of experiments proposed by Muste et. al. (2001) were conducted at IIHR-Hydroscience and Engineering laboratory in a 10m long, 0.61m wide and 0.5m deep, recirculating tilting open channel flume (Figure 1).

Laser Doppler Velocimetry (LDV) was used to measure the velocities in the water column. LDV measurements were done with a two-component fiber optic LDV system of conventional design. The LDV principles, operation and output are relatively followed the standard procedures and will not be detailed herein. At each measurement point, 15,000 samples are obtained and a standard procedure is used to determine the averages.

Large-scale particle image velocimetry (LSPIV) was used for measurements on the free surface. This method is an extension of conventional PIV for velocity measurements in large-scale flows (Fujita et al., 1998). While the image- and data-processing algorithms are similar to those used in conventional PIV, adjustments are required for illumination, seeding, and pre-processing of the recorded images.

A digital camera (Sony DCR-TRV320) is used for recordings. Two quartz-halogen photographic lamps with diffusers are used to illuminate the selected area. The transparent walls of the channel were covered by black masks so that there was a 2 cm opening at the both sides of the channel in the vicinity of the water surface plane (Figure 2). Proceeding in this way, only water surface region was illuminated and good contrast was obtained.

The seeding material for LSPIV was Styropor® expandable polystyrene which is produced by BASF with a bulk density of 12.5 kg/m^3 and diameters of 2 to 3 mm is used. Flow images recorded at 30 Hz were subsequently digitized in 640 by 480 pixels of 8-bit, gray-level resolution images and processed with the PIV analyzing software EdPIV®.

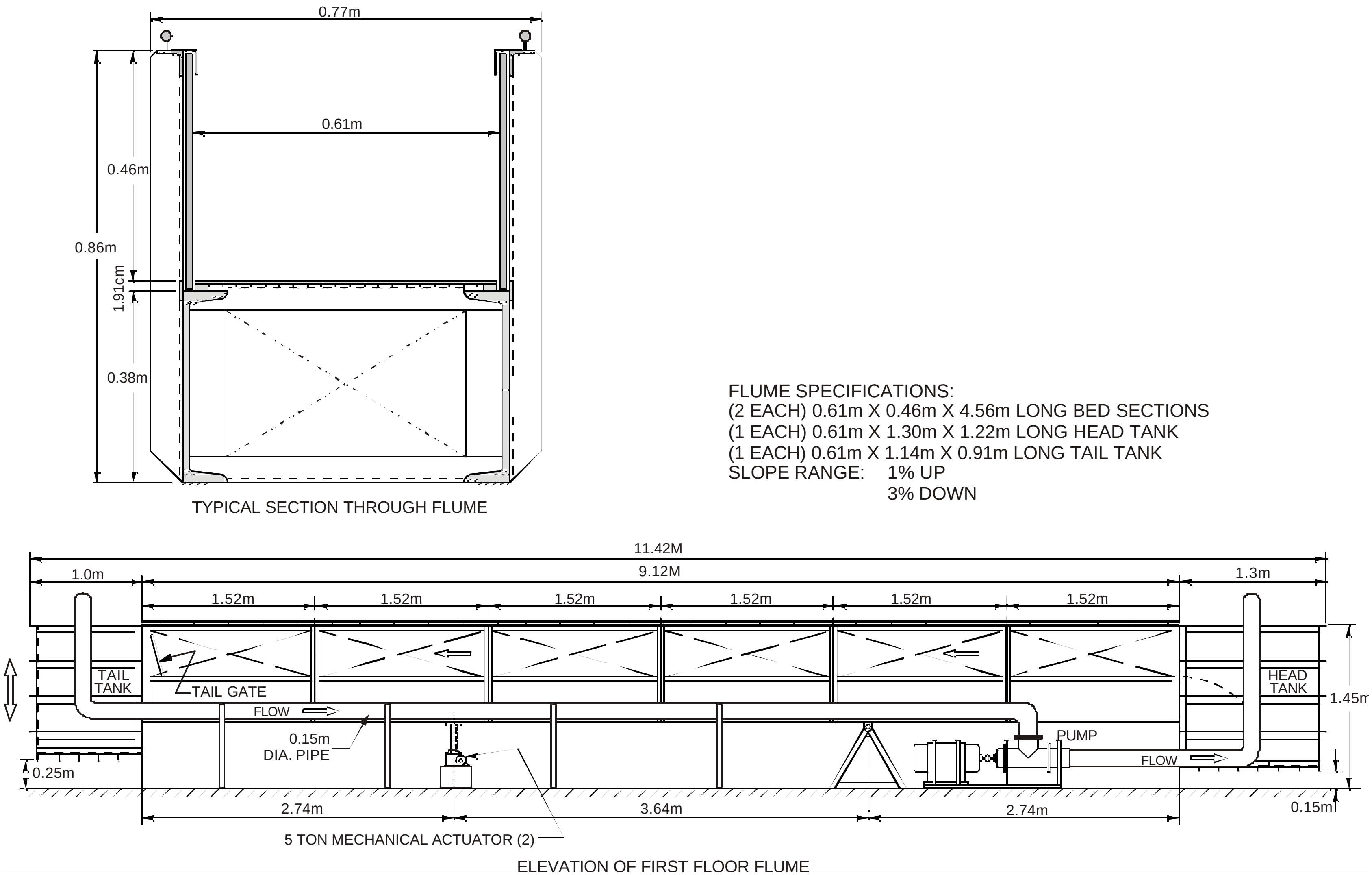

Figure 1. Open channel flume used in experiments

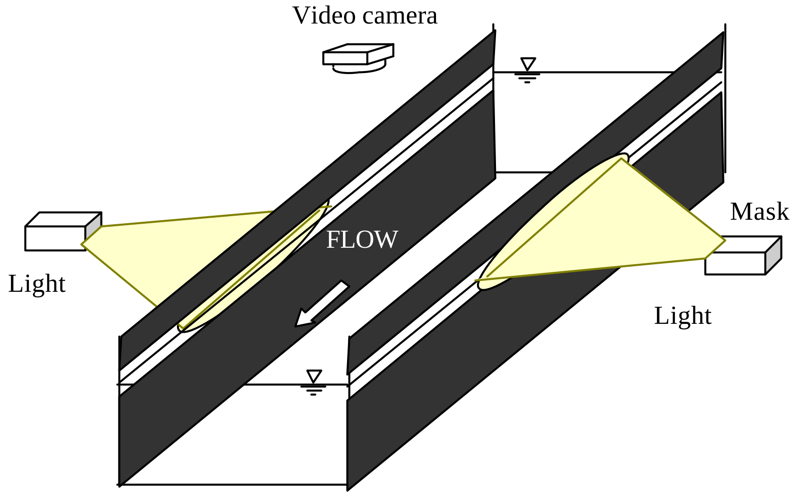

Figure 2 LSPIV system

EdPIV uses single-exposed multiple frames, as opposed to the multi-exposure single frame procedure, where several exposures can superpose on the same frame (Raffel, 1997). This approach is a straightforward application of PIV concepts to video-based recording systems. The analysis algorithm belongs to the so-called correspondence approach that performs correlation on the grey-level values contained in small regions, called interrogation areas.

The image processing algorithm used was developed by Gui and Merzkirch (2000). This algorithm implements the most recently developed PIV evaluation techniques, i.e., the central difference interrogation, continuous window shifting and image pattern correction. In essence, the algorithm finds the correlation between the image pattern enclosed in the *interrogation area* (IA) centered on a point a_{ij} in the image recorded at time t, and the IA centered at point b_{ij} in the image recorded at time $t+dt$, as illustrated in Figure 3. The correlation coefficient $R(a_{ij}, b_{ij})$ is a similarity index for the groups of pixels contained in the two compared IAs. In order to save computational time, correlation coefficients are only computed for points b_{ij} within a so-called *search area* (SA) defined around the point a_{ij}.

The two pictures in Figure 3 depict moving foam patterns on two successive video frames separated by a time interval dt. The Interrogation Area (solid square) defines the size of the foam patterns taken into account to identify the displacements. The Search Area (dotted circle) defines the area that is searched for possible displacements. To save computation time, only a portion of the image is searched. The arrow from a_{ij} to b_{ij} represents the identified displacement.

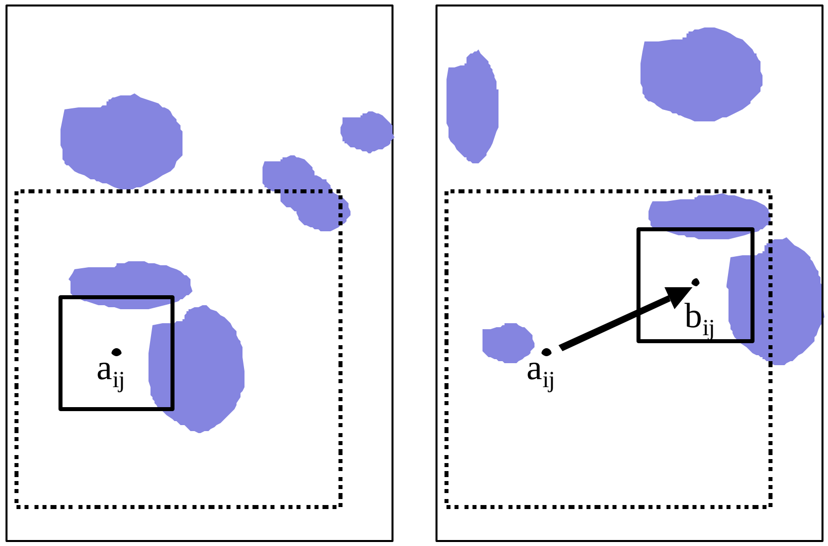

Figure 3. Sketch illustration of the algorithm used to identify the flow tracer displacement

The size and the shape of the SA are chosen on the basis of a priori knowledge of the flow field, such as the direction and magnitude of the mean flow. The most probable displacement of the fluid from point a_{ij} during the period dt is the one for which the correlation coefficient $R(a_{ij}, b_{ij})$ is maximum. A parabolic interpolation is used to determine the displacement with sub-pixel accuracy. Fujita and Komura (1994) show that particle-image displacements of about 0.2 pixels can be captured using this parabolic fitting when displacement gradients are relatively small. When several successive frames are available, as it is in our case, the most probable displacement is assessed using the maximum average coefficient of correlation computed over the complete sequence of images. Velocity vectors are derived from these displacements by dividing them by dt, the time between successive frames. The final vector field density is dependent on the choice of selection of the pitch, which defines the computational grid for the analyzed imaged area. Given the statistical approach used to determine the displacements and given the imperfections of the recorded images, it is possible to obtain spurious velocity vectors. Numerous post-processing routines are available to detect such vectors (see Raffel et al, 1998).

In our case, post-processing consisted simply of i) considering as spurious the vectors of less than 0.2 ms^{-1} and ii) interpolating linearly the missing grid points along current lines.

The code that was used for the LSPIV analysis EdPIV® has IMG correction, Boundary Mask, Background removing and error detection and error correction options. In the analysis of the data presented here, only error detecting option was used to detect erroneous vectors.

1.2. EXPERIMENTS

The experimental set conducted so far consists of 3 major flow categories:

A. Flat bed flows
B. Flow over discrete roughness elements (Ribs)
    1. k-type roughness-I
    2. k-type roughness-II
    3. d-type roughness
C. Flow over large scale roughness
    1. Smooth dune surface
    2. Roughened dune surface
        a. Wiremesh
        b. Sand

A. Flat Bed Flow

Experiments conducted with flow over flat/smooth bed is summarized in Table 1.

Table 1 Flat Bed Experiments

Code	d (m)	u_o (m/s) *	Fr	Re	AR	S_o
Ocf2-5	0.025	0.500	1.01	12500	24.4	$6.81x10^{-04}$
Ocf2-5	0.025	0.200	0.40	5000	24.4	$6.81x10^{-04}$
Ocf2-5	0.025	0.100	0.20	2500	24.4	$4.32x10^{-02}$
Ocf2-5	0.025	0.050	0.10	1250	24.4	$8.58x10^{-02}$
Ocf6	0.060	0.500	0.65	30000	10.2	$3.83x10^{-04}$
Ocf8	0.080	0.500	0.56	40000	7.6	$1.70x10^{-04}$
Ocf10	0.100	0.500	0.51	50000	6.1	$1.70x10^{-04}$
Ocf16	0.160	0.500	0.40	80000	3.8	$8.50x10^{-05}$
Ocf19	0.190	0.500	0.37	95000	3.2	$3.19x10^{-04}$

(*): Data not processed yet

In the above table, *Fr* and *Re* are Froude number and Reynolds number based on flow depth, *d*, respectively. *AR* stands for the aspect ratio, which is the ratio of channel width (61cm) to the flow depth. S_o shows the channel slope. u_o is the free surface velocity. Exact values for u_o are provided after LSPIV data is analyzed. At the present time the provided values are rough values for the cases whose LSPIV data is not analyzed.

B. Flow over Discrete Roughness Elements (Ribs)

Rectangular ribs of 1cm x 1cm in cross-section and 61cm in length are fixed over the smooth channel bottom. The placement frequency of the ribs was changed from 4.5cm to 18cm, to obtain different flow conditions. λ values of 9, 18, 4.5cm are used for the cases k1, k2 and d1 respectively.

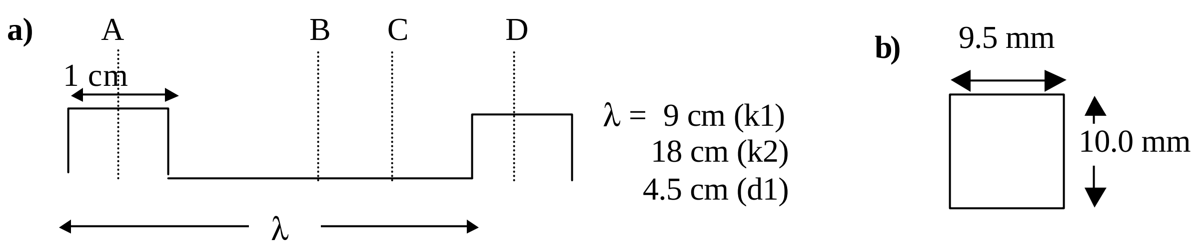

Figure 4. a) Longitudinal and **b)** cross-sectional view of ribs

Flow conditions for each flow case are summarized in following tables

Table 2 k-type roughness –I

Code	d (m)	u_o (m/s)*	Fr	Re	AR	S_o
Rib10	0.100	0.500	0.505	50000	6.10	3.48×10^{-03}
Rib08	0.080	0.439	0.496	35120	7.62	3.27×10^{-03}
Rib06	0.060	0.350	0.456	21006	10.16	***

(*): Data not processed yet

Table 3 k-type roughness -II

Code	d (m)	u_o (m/s) *	Fr	Re	AR	S_o
rib10	0.100	0.508	0.513	50800	6.10	2.49×10^{-03}
rib08	0.080	0.462	0.522	36960	7.62	2.55×10^{-03}
rib06	0.060	0.350	0.456	21000	10.16	2.61×10^{-03}

(*): Data not processed yet

Table 4 d-type roughness

Code	d (m)	u_o (m/s) *	Fr	Re	AR	S_o
Rib10	0.100	0.500	0.505	50000	6.10	-
Rib08	0.080	0.500	0.564	40000	7.62	-
Rib06	0.060	0.500	0.652	30000	10.16	-

(*): Data not processed yet

C. Flow over Large-Scale Roughness (Dunes)

A train of 22 dunes with a geometry shown in Figure 5 is used to investigate the flow over dunes. For the flow cases with wiremesh, a wiremesh was placed over the surface of the dunes. To obtain sand roughness, a layer of sand particles of 1.65-2mm diameter were glued over the dune surface.

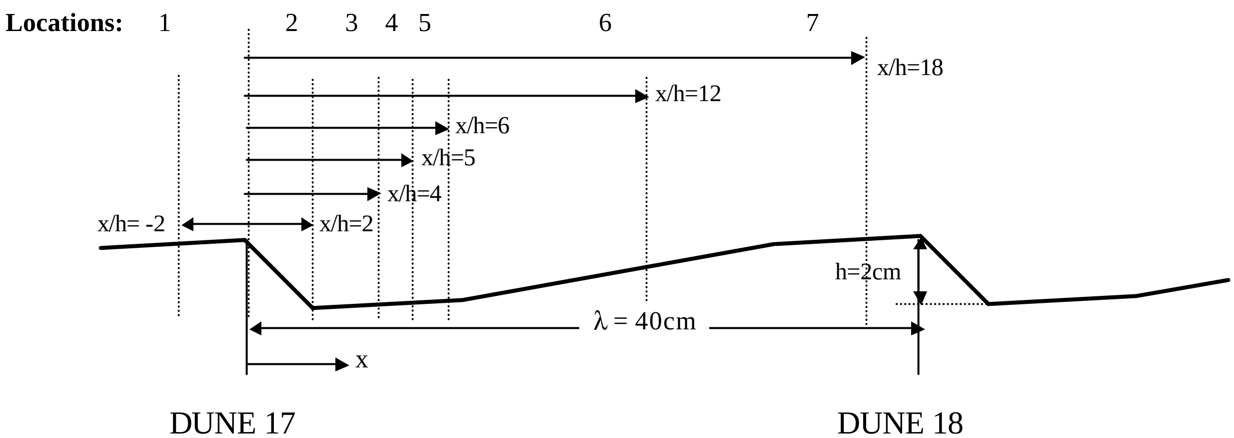

Figure 5 Geometry of dunes, and 7 locations for LDV vertical profiles

In Table 5 flow conditions obtained for experiments are shown. Experiments for Depth 3 and 6 have been discarded due to small aspect ratios.

Table 5 Flow over dunes experiments

Flow Cases	Depth at crest	u_o (m/s) *	Fr	Re	AR	S_o
Depth 1	0.118	0.5	0.465	59000	5.17	-
Depth 2	0.078	0.5	0.572	39000	7.82	-
Depth 3	0.251	0.5	0.319	125500	2.43	-
Depth 4	0.165	0.5	0.393	82500	3.69	-
Depth 5	0.06	0.5	0.652	30000	10.16	-
Depth 6	0.202	0.5	0.355	101000	3.02	-
Depth1 sand	0.118	0.5	0.465	59000	5.17	-
Depth1 Wire Mesh	0.118	0.5	0.465	59000	5.17	-

(*): Data not processed yet

1.3. EXPERIMENTAL PROCEDURE

Velocities throughout the water column, including the free surface were obtained by combining Laser-Doppler Velocimetry (LDV) and Particle Image Velocimetry (PIV) in an arrangement illustrated in **Figure 6**. LDV measures velocities in the column of water (in a vertical), while PIV measures free surface velocities. It is worth noting that that there is no better alternative instrument to measure free-surface velocity. The two non-intrusive measurement techniques are able to fully document instantaneous and mean flow characteristics at the free surface and in the water column with relatively high temporal and spatial resolutions.

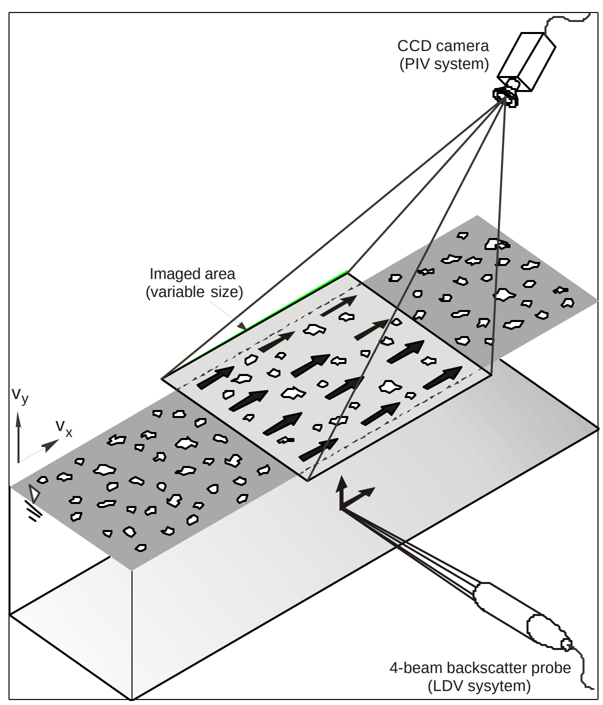

Figure 6. Laboratory experimental arrangement

In addition, video recordings of the free surface texture were taken to document any particular signature of the internal and secondary flow parameters on the aspect of the free surface.

For each flow cases LSPIV and LDV tests were conducted and the surface texture was recorded. Experiments were conducted in the following order

1. Obtaining the flow conditions: Channel slope, flow depth and surface velocity are adjusted iteratively. Starting from a rough numbers for S_o, d and u_o, the final channel slope is obtained. Flow depth is changed by adding or removing water from the channel, and surface velocity is controlled by decreasing or increasing the circulating-pump frequency.
2. LDV measurements: After the flow is set, the water is seeded and experiments are conducted.
3. Surface texture recording obtained with the camera placed above the flow and strategically positioned lights.
4. LSPIV measurements: Flow is seeded with styropor particles. Flow surface is illuminated from sides by halogen lamps with diffusers. Recording is done by a camera set above the channel.

For details of experimental settings, see attached paper (Polatel, 2003).

2. DATA ANALYSIS

The time period from the project inception was used to setup the LDV and LSPIV systems for the specific conditions required by the project, to train the research team with the instrument operation, and to conduct the experiments. Data processing is currently in progress. Analysis of the experiments will proceed using the sample analysis provided in Appendix A.

Based on the preliminary results obtained so far, a publication for the Student competition of the International Association for Hydraulic Engineering and Research (IAHR) Congress in Thessaloniky (Greece) was submitted by the PhD student conducting the research (Polatel, 2003). The submitted paper is provided in Appendix B. The main findings of the preliminary results are summarized below:

- Surface velocity reacts to changes in the channel bed variation and roughness;
- Secondary currents are ubiquitous in flume experiments and they affect selectively the velocity profiles in the water column, in direct relationship with the position of the measured vertical.
- When direct action on the free surface is absent (e.g., wind shear), the free surface appearance is mainly related to the large-scale turbulence structures acting in the flow.

3. REFERENCES

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Fujita, I., Muste, M. and Kruger, A. (1998). "Large-Scale Particle Image Velocimetry for Flow Analysis in Hydraulic Applications," *J. Hydr. Res.*, 36(3), pp. 397-414.

Gui, L. and Merzkirch, W. (2000). " A Comparative Study of the MQD Method and Several Correlation-Based PIV Evaluation Algorithms," *Experiments in Fluids*, 28, pp. 36-44.

Raffel, M., Willert, C. and Kompenhaus, J., 1997 : *Particle Image Velocimetry*. Spring-Verlhag, 253 pp.

Muste, M., Bradley, A., Kruger, A., Cheng, R. T. (2001). "Complementary Investigation for Implementation of Remote, Non-Contact Measurements of Streamflow in Riverine Environment," USGS/National Institutes for Water Resources, *Proposal*, IIHR-Hydroscience & Engineering, Iowa City, IA.

APPENDIX A

Sample of Experimental Result Analysis

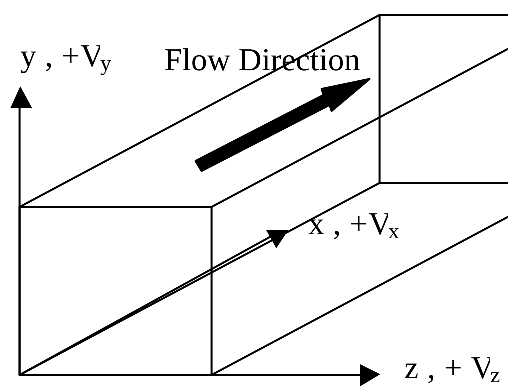
LSPIV and LDV Analysis
Flow Case: Ocf-Depth 10

A. GENERAL CONSIDERATIONS

1. Experimental conditions

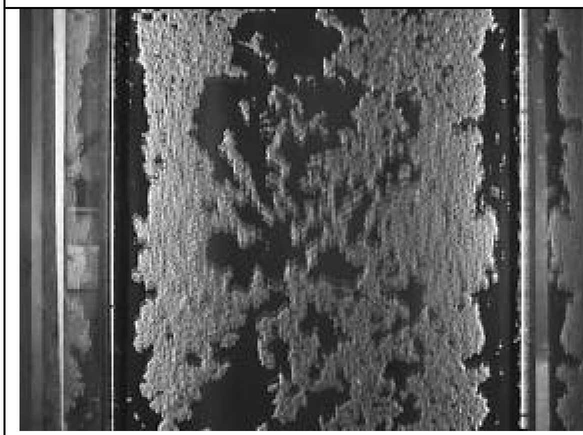
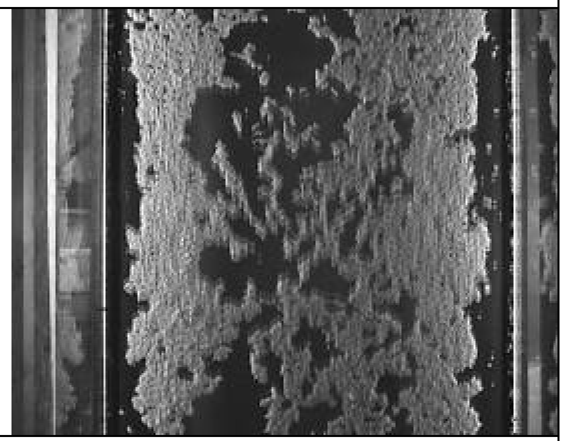
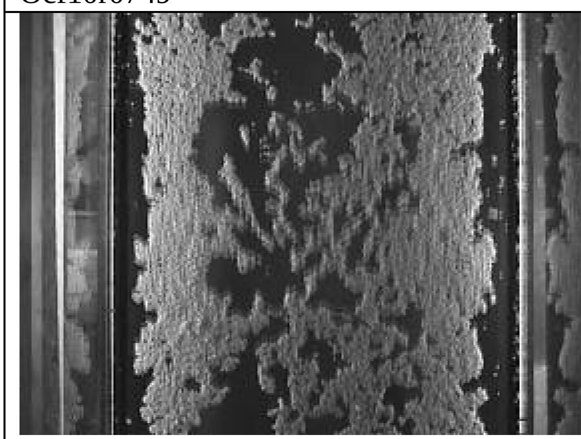
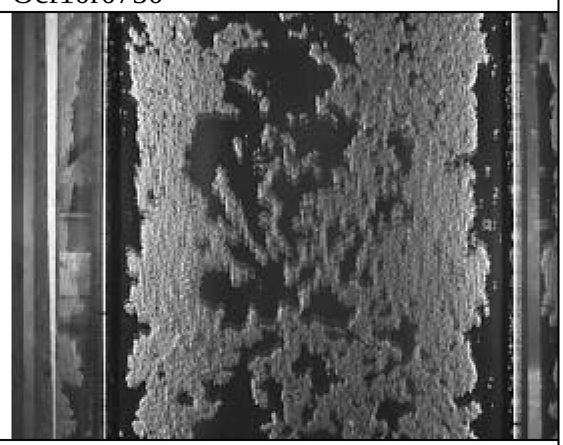
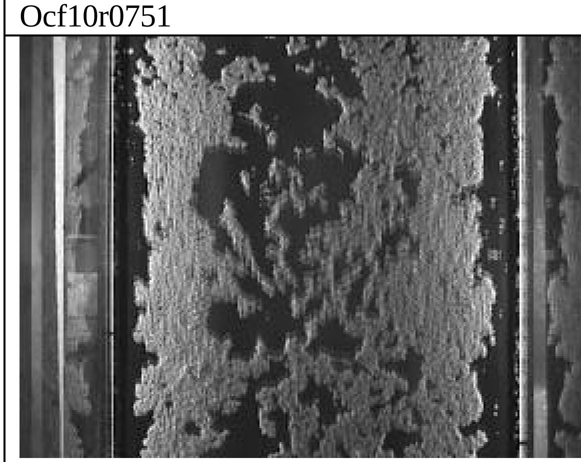
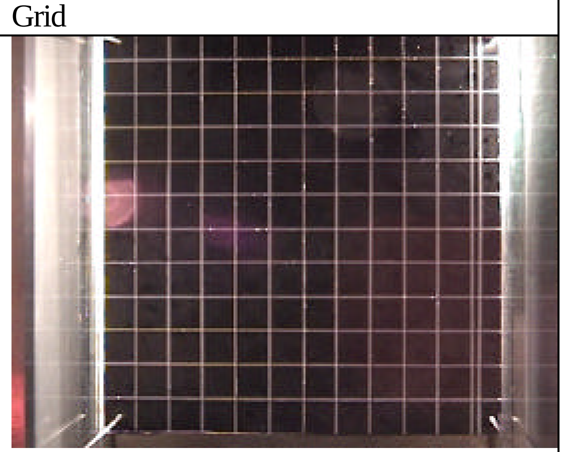
Recording: manual focus
Illumination: Black panels at sides, side illumination from both sides
Flow condition: Flat smooth bed, VFD readout 24.2%, Depth 10cm, Slope 0.000573
Friction velocity, u_*=0.02m/s

2. Coordinate System



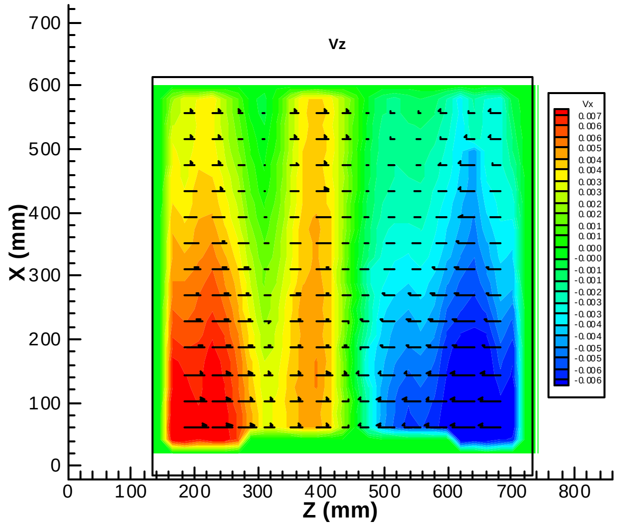
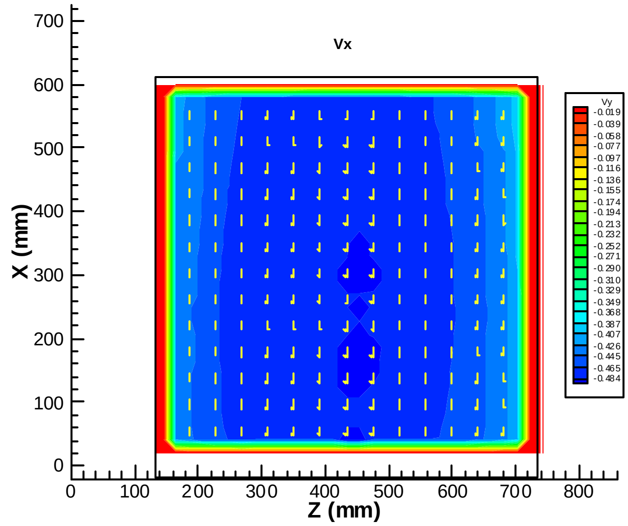
B. LSPIV RESULTS

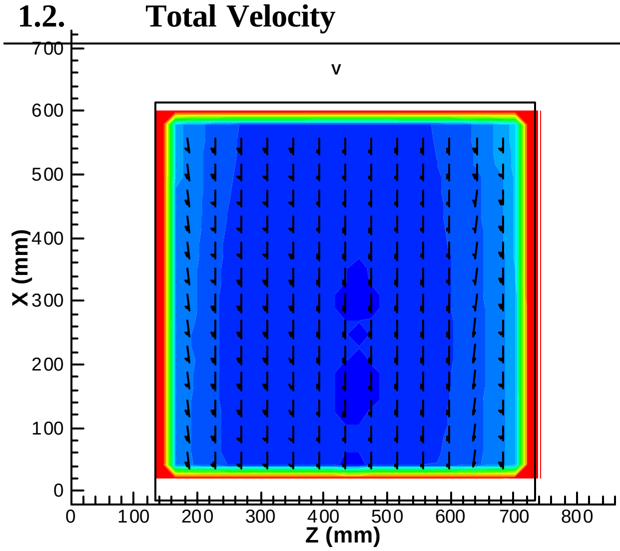
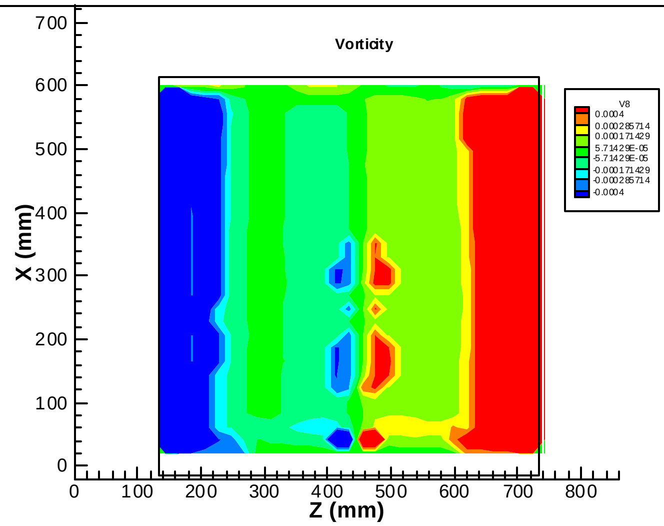
1. Samples of de-interlaced images

Ocf10r0747	Ocf10r0748
	
Ocf10r0749	Ocf10r0750
	
Ocf10r0751	Grid
	

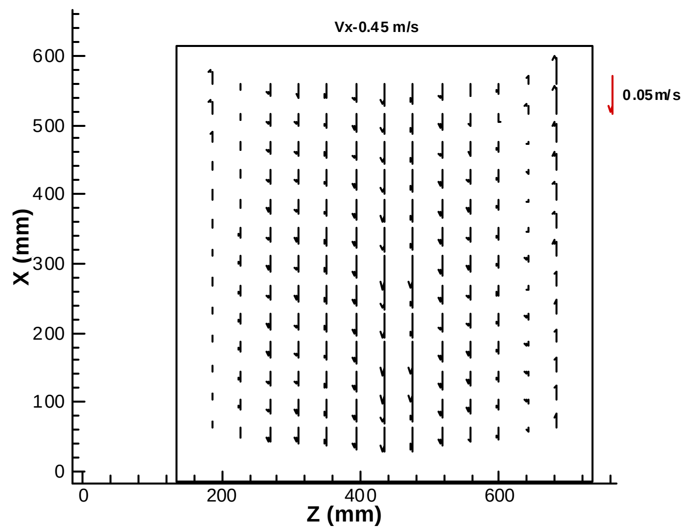
2. Mean vector fields - data for free surface at 7m from the flume entrance

PIV processing parameters: Interrogation window size: 64x64; image scaling : 774 pixels/m;

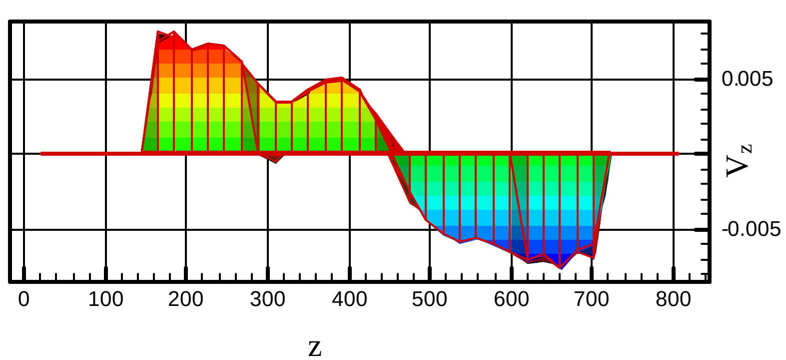
Mean Vz	**1.1. Mean Vx**
	

1.2. Total Velocity	**1.3. Vorticity**
	

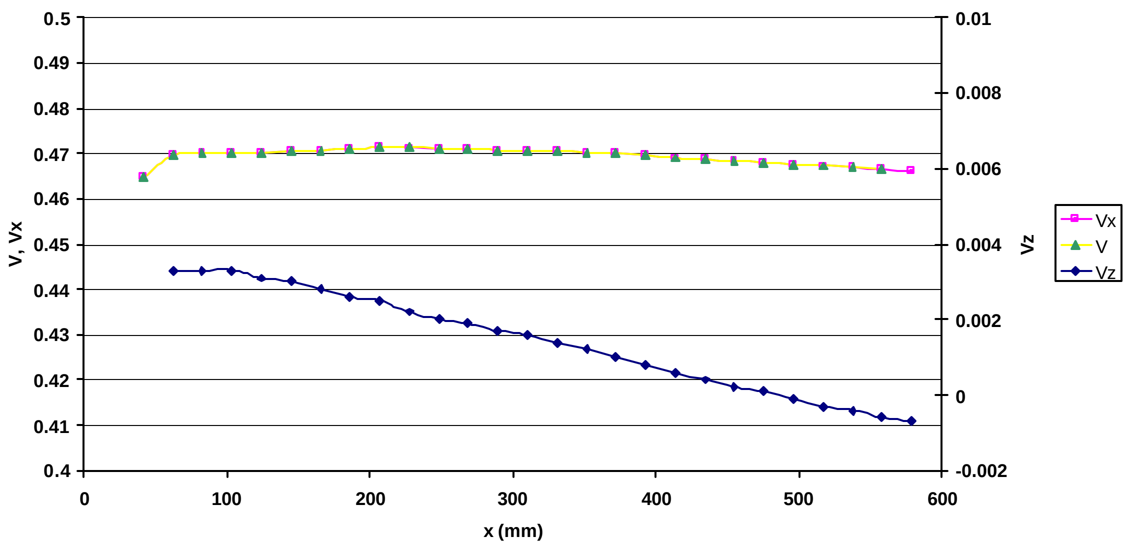
Zoomed-in Streamwise velocity component over the LSPIV test section
(0.45m/s subtracted from the mean streamwise velocity component)



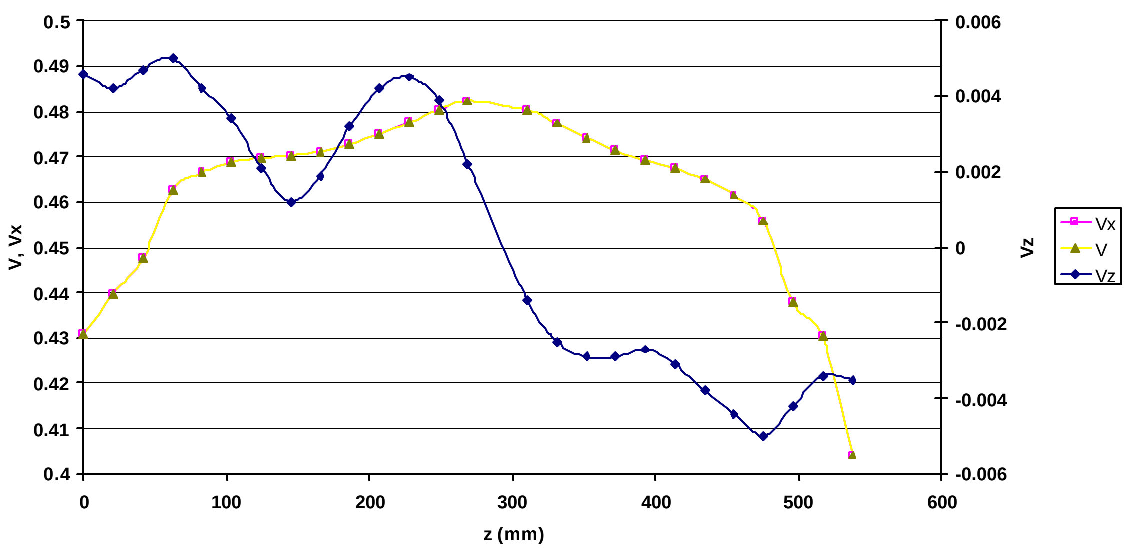
Spanwise velocity component distribution in the test section



Distribution of mean velocity profiles in the streamwise direction

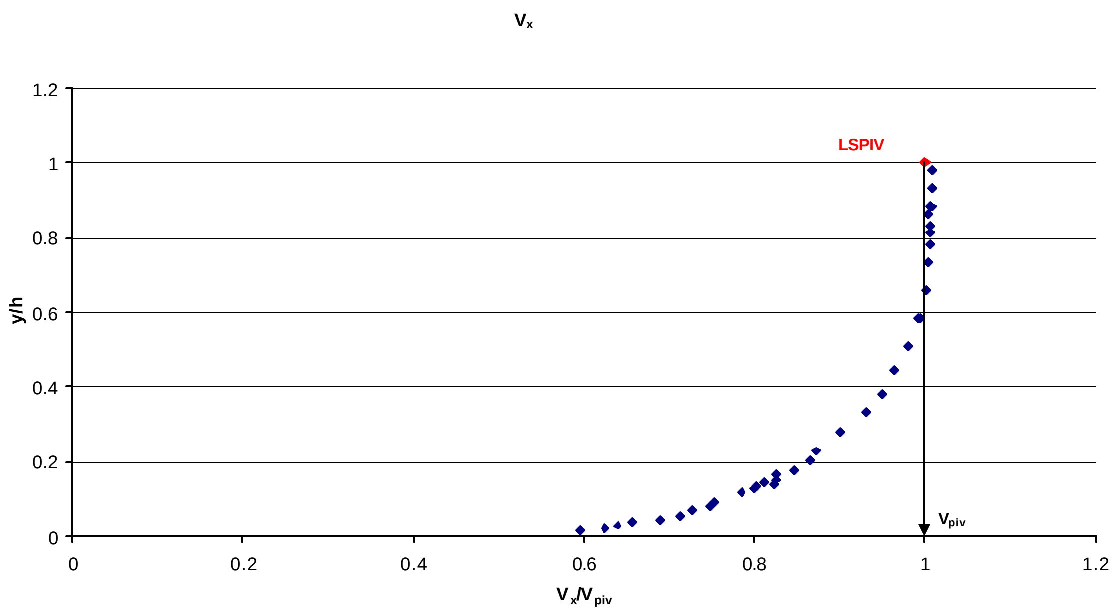


Mean velocity components in the spanwise direction

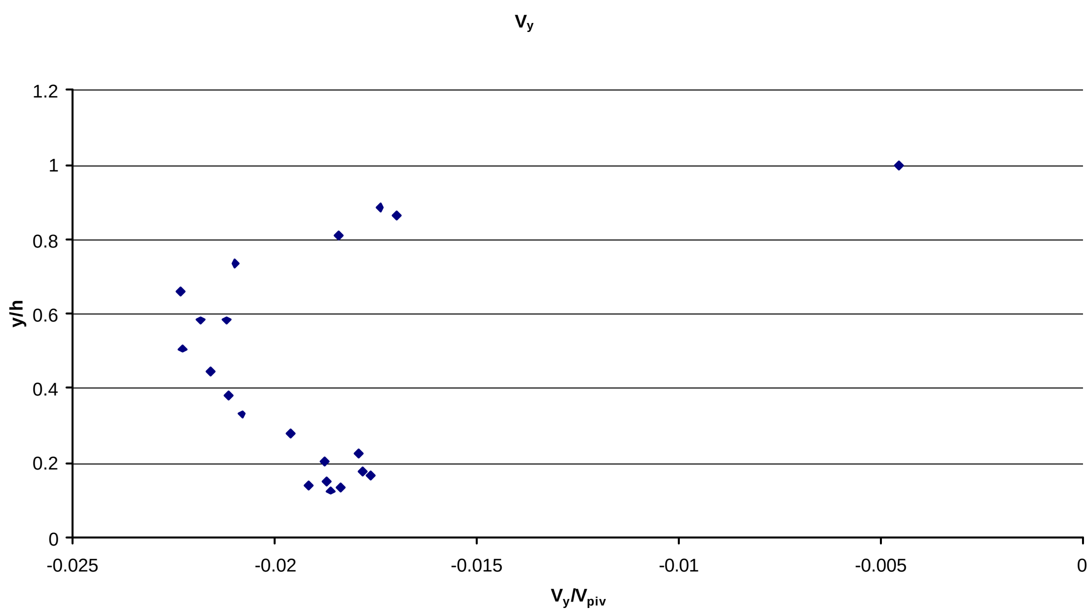


C. LDV RESULTS

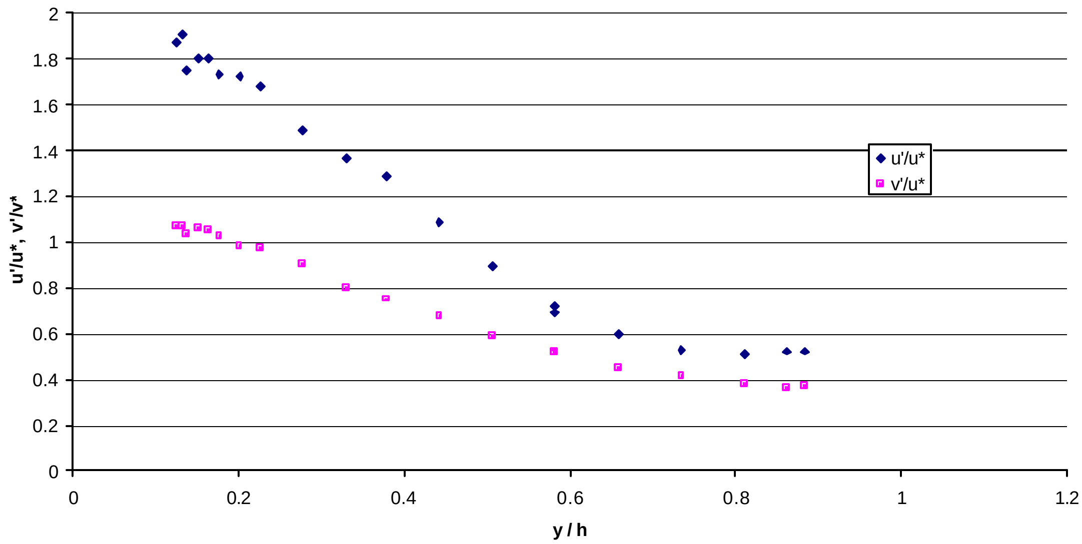
Mean streamwise velocity distribution over the depth



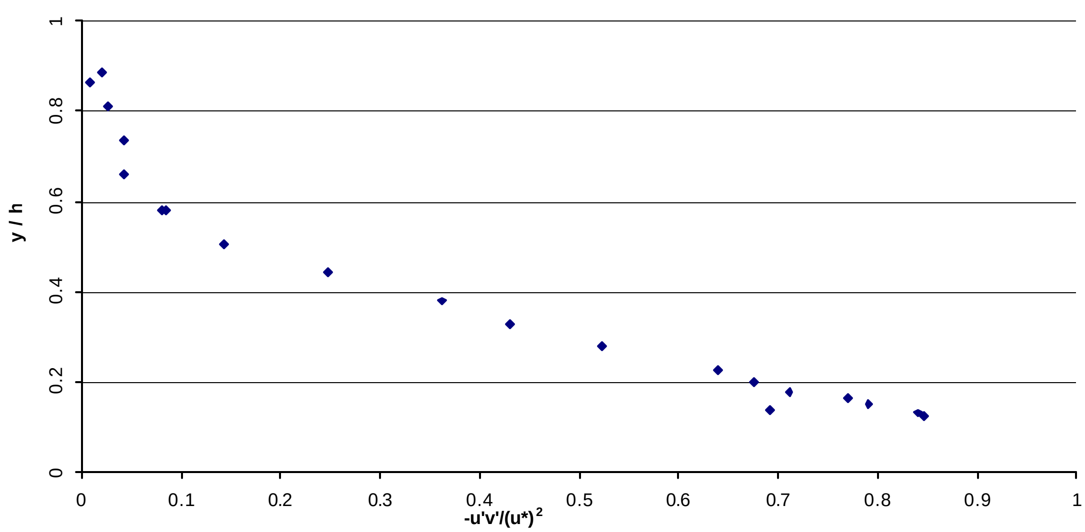
Mean vertical velocity distribution over the depth



Turbulence intensity distribution over the depth

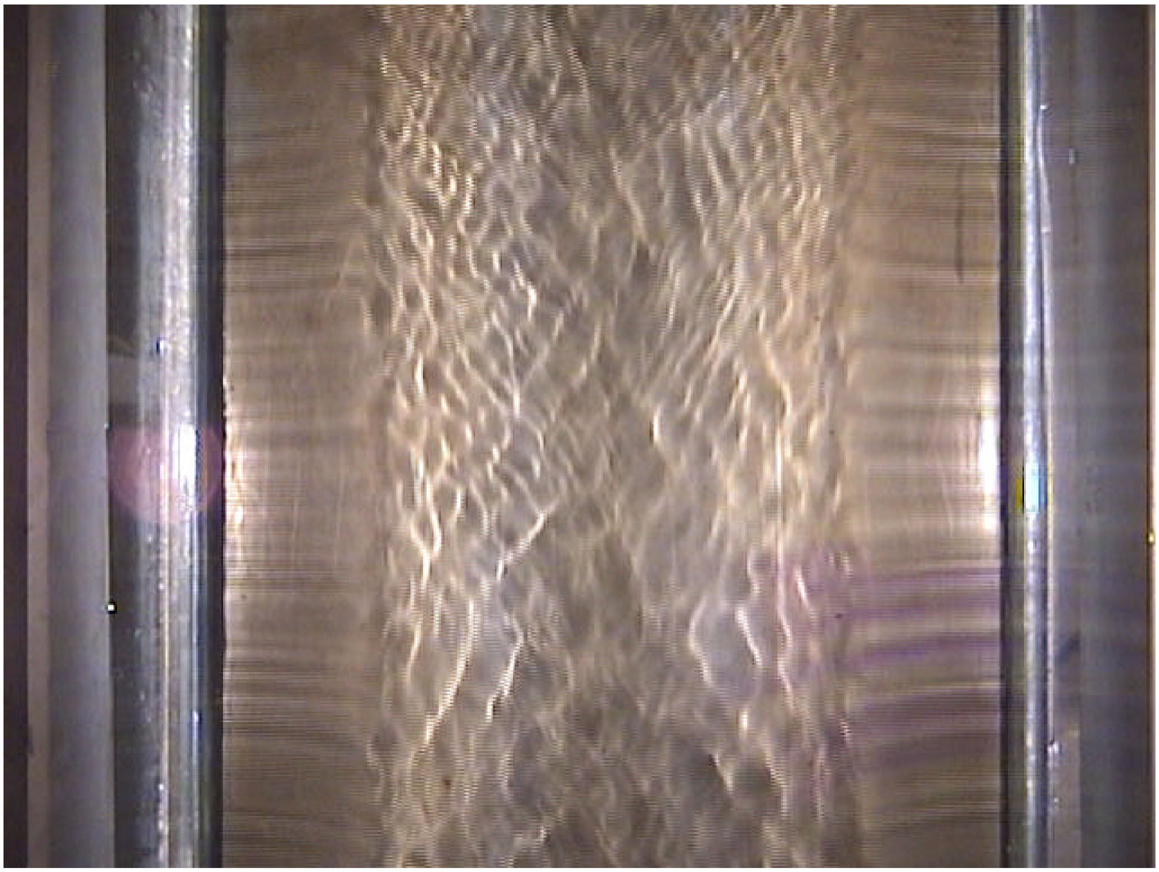


Reynolds stress distribution over the depth



D. FREE-SURFACE TEXTURE

Video frame of the free surface



APPENDIX B

Additional Reference

SIGNATURE OF BED CHARACTERISTICS ON FREE SURFACE VELOCITY IN OPEN CHANNEL FLOWS

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ABSTRACT

Discharge estimation is the essential part of any hydraulics problem related with rivers, like sediment or pollutant transport. Traditional methods, used to determine river discharge have many shortcomings. A non-contact method with lower cost, better accuracy and less hazards than that of traditional stream-gaging method are currently investigated. One of these methods, called "indexing", aims to plot all the velocity profile for known bed characteristics by using only one pointwise velocity measurement. The essential part of this method is to estimate the non-dimensional velocity distribution for given bed characteristics. Having the structure of the velocity distribution, only one pointwise velocity measurement will be enough to plot velocity profile. Taking the free surface velocity as indexing velocity has advantages in the aspect of appropriateness to non-contact measurement techniques. However, both free surface velocity and velocity profile are sensitive to many factors together with bed characteristics. From the perspective of the non-contact, remote measurements of the free surface, the effects of related parameters on the free surface velocity and velocity profile have become an important issue to be investigated. Here the summary of some preliminary results related to this topic, obtained from the ongoing studies at IIHR- Hydroscience and Engineering laboratories are presented. Among the parameters involved, bedform effect is discussed in this paper. Two tests, one for the flow on smooth straight channel bed and the other for the flow over sand dunes are presented. The results of the observations show that there is a signature of the spatial changes in the channel bed on the free surface velocity. The quantitative description of this signature is left as a future work for the subsequent publications.

Keywords: Open channel flow, Free surface velocity, Indexing, Laser Doppler Velocimetry (LDV), Large Scale Particle Image Velocimetry (LSPIV), Sand dunes.

INTRODUCTION

The idea behind the remote discharge measurements is to integrate remotely obtained bed characteristics and velocity distribution information. For these methods, it is crucial to have a unique and accurate relationship between the velocity distribution and flow conditions (secondary currents, large-scale turbulence, wind effects) and bed forms.

Extensive amount of studies in the literature is dealing with estimating the velocity distribution by using a pointwise measured velocity for a given bed configuration. In the present context, the term "indexing" is used to relate the velocity distribution over the depth to the velocity measured at a point in the water column (e.g. surface, maximum or depth averaged velocity).

Indexing has become important from the perspective of new measurement technologies that are using one point velocity measurement to characterize velocity distribution over the depth. Newly developed Large Scale Particle Velocimetry (LSPIV) (Muste et al., 2001), Radar (Cheng, 2001), Horizontal Acoustic Doppler Currentmeter Profiler (HADCP) techniques provide sufficiently accurate one-point measurements for this purpose.

Studies taking different velocities like maximum or free surface velocities as indexing velocity exist in the literature (Chiu, 2002). Taking maximum velocity as indexing velocity has some shortcomings in the aspect of uncertainties in determining magnitude of the maximum velocity together with its position.

Free surface velocity as indexing velocity on the other hand has advantages in the aspects of convenience in finding location and magnitude of the free surface velocity and appropriateness to non-contact measurements. Due to the limitations of the measurement techniques, the free surface couldn't be attained at the past. However, recently developed methods such as radars and image velocimetry methods make it possible to measure free surface velocity and subsequently determine discharges.

Another factor that underlines the need to study on relationship between free surface velocity-velocity distribution is that there are various published accounts showing that the state of the free surface (i.e., waviness, ripples) in open channel flows has peculiar relationships with the velocity distribution in the column of water below it. Even in the simpler case of open-channel flume flows on smooth beds there is no agreement on the appearance of the mean velocity profile near the free surface. This situation is explained by the sensitivity of the near-surface flow region to secondary factors such as waviness of the free surface, secondary currents, bedforms, large-scale turbulence, and sidewall (banks) effect (Muste, 2001).

From the perspective of the non-contact, remote discharge measurements, relationship between the free surface velocity and velocity distribution, and identification of effects of secondary factors on free surface velocity has become an important issue to be investigated.

For this purpose, a set of experiments is planned, in which the effects of aspect ratio, bed characteristics and wind effect will be investigated. In accordance with the motivation of non-contact measurements, both free surface velocities and velocity distributions are measured remotely in the lab. To measure the free surface velocity LSPIV method is selected since it is the most suitable technique available. To obtain the velocity distribution LDV method is used due to its non-intrusivity, accuracy and directional sensitivity. Here, as a preliminary discussion of this extensive study, effect of channel bed configuration on free surface velocity will be discussed.

EXPERIMENTAL SETUP AND FLOW CONDITIONS

The experimental arrangement of Laser-Doppler Velocimetry (LDV) and Large Scale Particle Image Velocimetry (LSPIV) systems used to obtain velocities throughout the water column, including the free surface is illustrated in Figure 1. The camera mount and the fiberoptic-probe mount will be integrated in a platform designed and manufactured at IIHR. LDV will be used for measuring velocities in the column of water (in a vertical), while LSPIV will be used for free surface measurements. It is worth noting that that there is no better alternative instrument to measure free-surface velocity. The two non-intrusive measurement techniques are able to fully document instantaneous and mean flow characteristics at the free surface and in the water column with relatively high temporal and spatial resolutions.

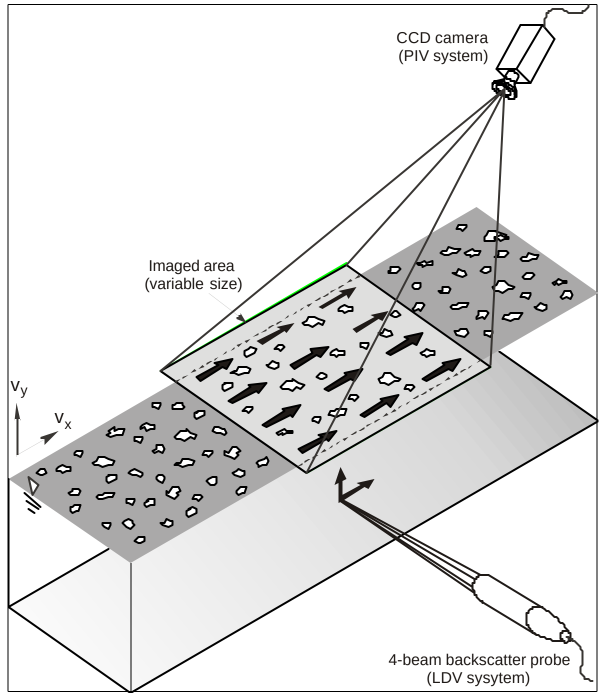

Figure 1. Experimental arrangement.
Courtesy Muste et al. (2001)

The proposed set of experiments have been conducted at IIHR- Hydroscience and Engineering laboratory. Experiments were conducted in a 10m long, 0.61m wide and 0.5m deep, recirculating tilting open channel flume. Hydraulic conditions for the test conducted are summarized in Table 1. For DUNE10 case, velocity and depth at Location 1 as taken as characteristic velocity and depth.

Table 1. Hydraulic conditions

	h (m)	u_o (m/s)	Re	Fr	Aspect Ratio
Smooth Bottom (OCF10)	0.10	0.482	48200	0.49	6.1
Over Dunes (DUNE10)	0.118	0.479	56500	0.45	5.17

For the flow case DUNE10 a train of 22 dunes is used. The shape and the size of the dunes are identical to those used by Balachandar (2002) and shown in Figure 2. LDV measurements over one wavelength were done at 6 sections. LSPIV recordings also cover an area slightly larger than a dune wavelength.

LDV and LSPIV measurements are carried out in over the 17th and 18th dunes from the entrance of the channel. The measurements for OCF10 were done at the same distance from the entrance of the channel with DUNE10 case.

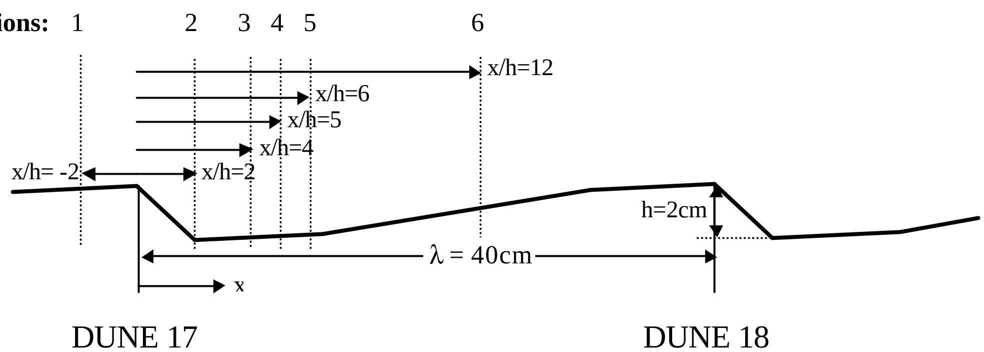

Figure 2. Geometry of dunes, and 6 locations for LDV measurements

LDV EXPERIMENTS

A two-component, two-color, fiberoptic-based LDV system (TSI 900-3) is used in the experiments. The system comprises of a L-70-2 two-watt argon-ion laser, a two component fiberoptic Colorburst™ transmitting optics, Colorlink™ receiving optics, IFA 655 signal processor (burst correlator), and FIND™ interfacing and data analysis software.

Two components of instantaneous velocities, the streamwise and the vertical, were measured with the LDV system. At each measurement point, 15,000 samples are obtained and a standard procedure is used to determine the averages. For both flow cases, LDV measurements are done at the centerline of the channel.

LSPIV EXPERIMENTS

A digital camera (Sony DCR-TRV900) is used for recordings. The imaged area set as it covers the entire area between the crests of dune 17 and 18. Two quartz-halogen photographic lamps with diffusers are used to illuminate the selected area. Flow images recorded at 30 Hz will be subsequently digitized in 640 by 480 pixels of 8-bit, gray-level resolution images and processed with the PIV analyzing software EdPIV®.

Transparent walls of the channel are covered by black masks so that there will be 2 cm openings at the both sides of the channel in the vicinity of the water surface. So only, the water surface region was illuminated by the lights.

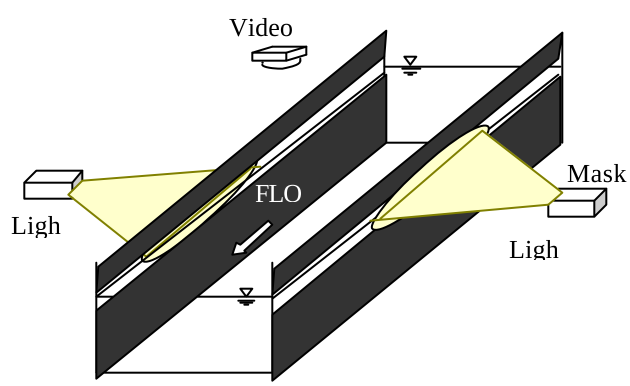

Figure 3. LSPIV

As a seeding material Styropor® expandable polystyrene which is produced by BASF with a bulk density of 12.5 kg/m^3, and diameters of 2 to 3 mm is used.

Although seeding is the very important part of LSPIV experiments, there is very little information about the behavior of floating seeds for LSPIV. Since the used seeds are very light, it is assumed that they follow the flow without disturbing it.

OVERVIEW OF RESULTS

In Figure 4, LDV and LSPIV measurements at the centerline of the channel are shown. LSPIV measurement is found as 0.482m/s, which is almost 0.02m/s smaller than the uppermost LDV measurement point, which is 0.5m/s. The mean velocity of the flow is found as 0.46 m/s.

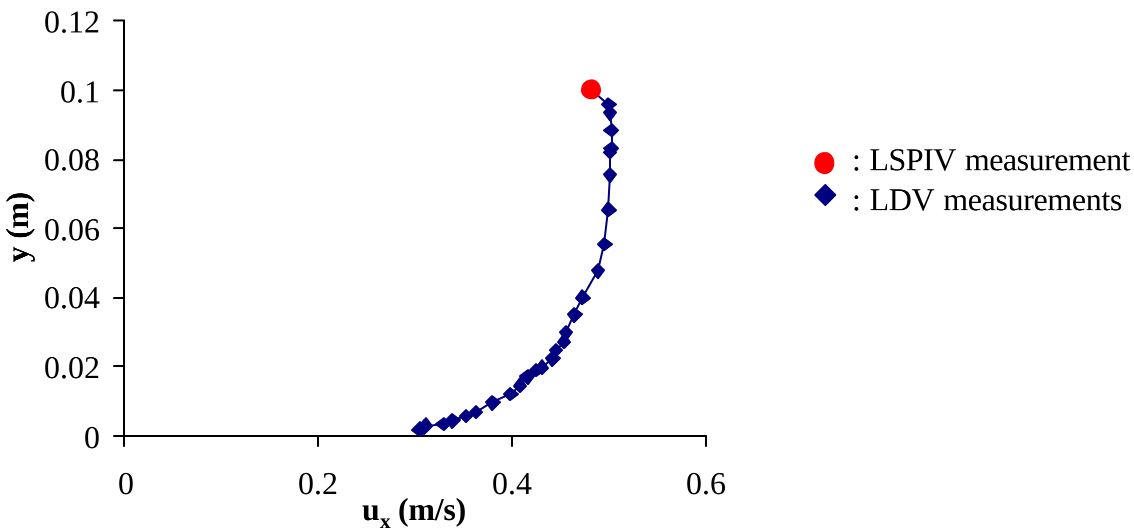

Figure 4 Case OCF10 velocity distribution in vertical direction at the channel centerline

LSPIV results for streamwise, u_x, and spanwise velocity, u_z, distributions are shown in Figure 5. The symmetry of profiles of u_x and u_z is the validation of the consistency of the LSPIV results. Symmetric nature of the u_z according to channel centerline is an indicator of secondary flow towards the centerline of the channel from the sides. There are two, close to symmetric local peak points in the distribution of u_z at each half of the channel cross-section. The discussion of possible reasons for these peaks, which also seen in DUNE10 case, is left for subsequent publications since it needs more data to be concluded.

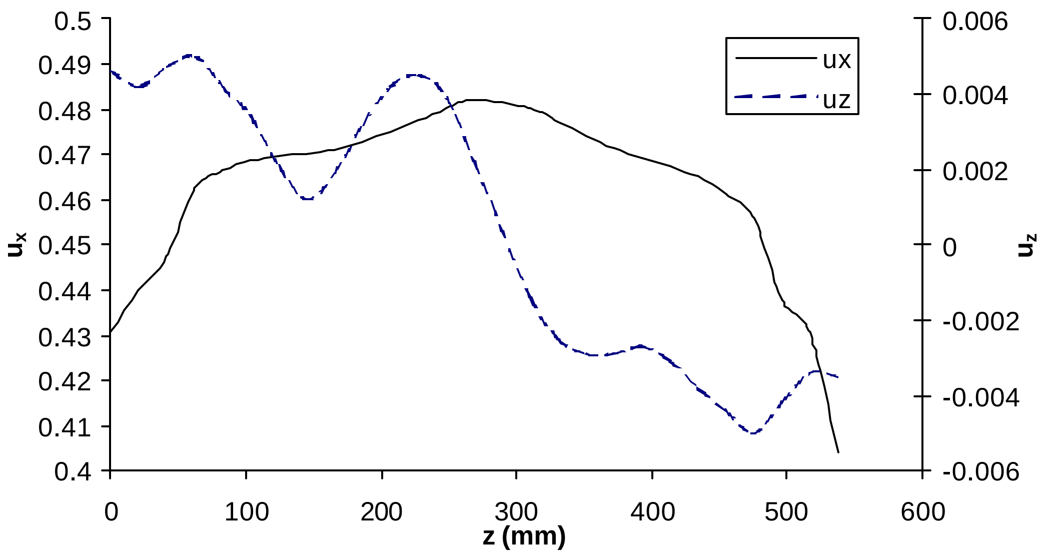

Figure 5 Case OCF10 Streamwise and spanwise velocity components along spanwise direction – LSPIV results

In figure 6, LDV and LSPIV measurements for the DUNE 10 case at the centerline of the channel are shown. The summary of the results for this case is given in Table 2. Profile shown for location 7 is the repetition of the one for location 1.

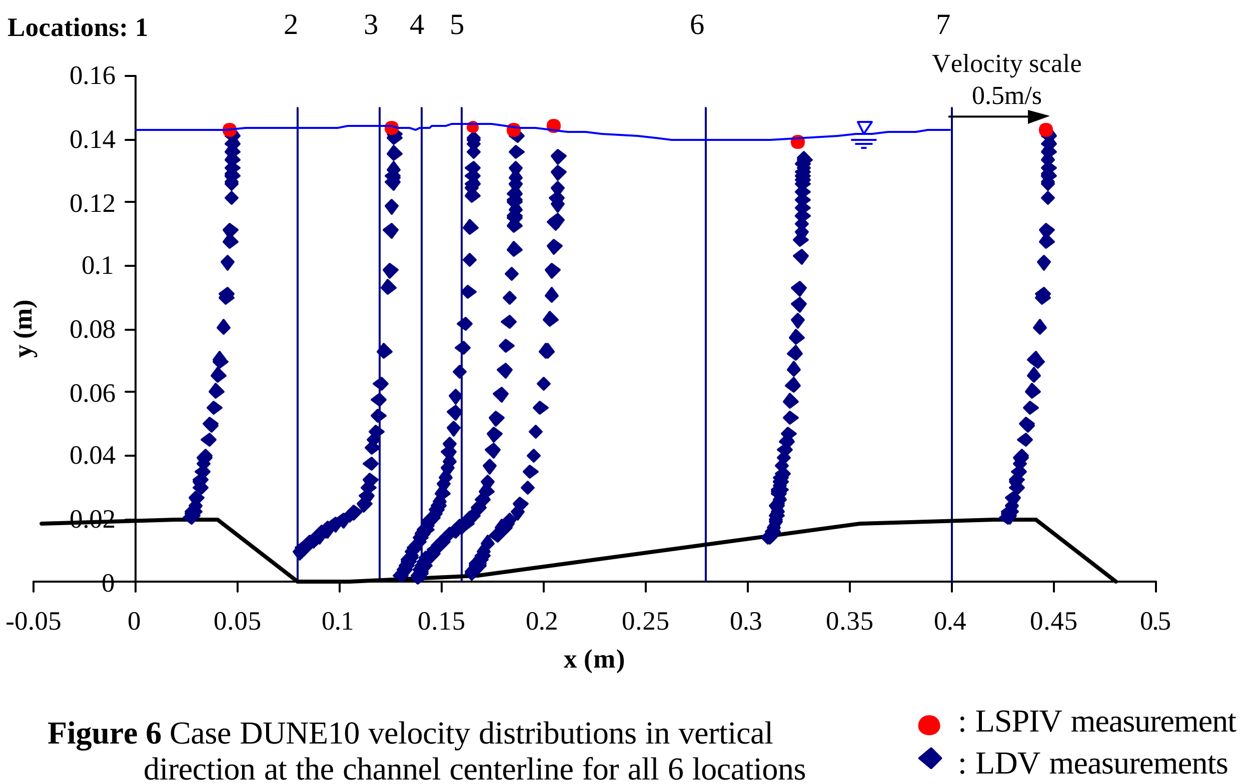

Figure 6 Case DUNE10 velocity distributions in vertical direction at the channel centerline for all 6 locations

Table 2. Summary of result for DUNE10

	u_{LDV} (m/s)	u_o (LSPIV) (m/s)	u_{mean} (m/s)
LOC1	0.475	0.456	0.422
LOC2	0.479	0.460	0.347
LOC3	0.479	0.469	0.371
LOC4	0.470	0.461	0.369
LOC5	0.459	0.461	0.378
LOC6	0.471	0.459	0.420

In Table 2, u_{LDV} shows the LDV measurements taken at the highest possible point. These values have importance in assessment of existence of bias in LSPIV values.

In Figure 7 and 8, streamwise and spanwise velocity distributionS at all 6 locations found by LSPIV are shown. Again, the symmetry in the distributions is the relative validation for the LSPIV method.

The important point that can be drawn from this graph is that even though the differences in the velocities for different locations are very small, they are following a pattern. As seen in Figure 7, velocities become larger at the locations with higher channel bottom elevation.

Another conclusion can be deduced from these graphs is, even the aspect ratio of the experimental conditions is much smaller than the values seen in natural rivers, surface velocity reacts to spatial changes in channel bottom.

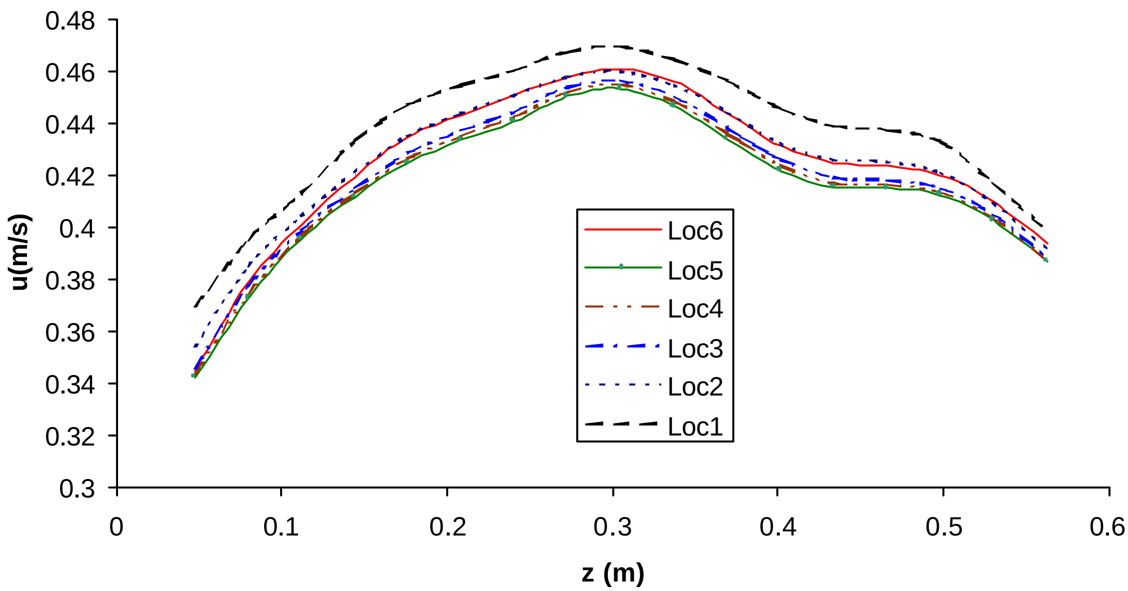

Figure 7 Case DUNE10 Streamwise velocity components along spanwise direction for all 6 locations – LSPIV results

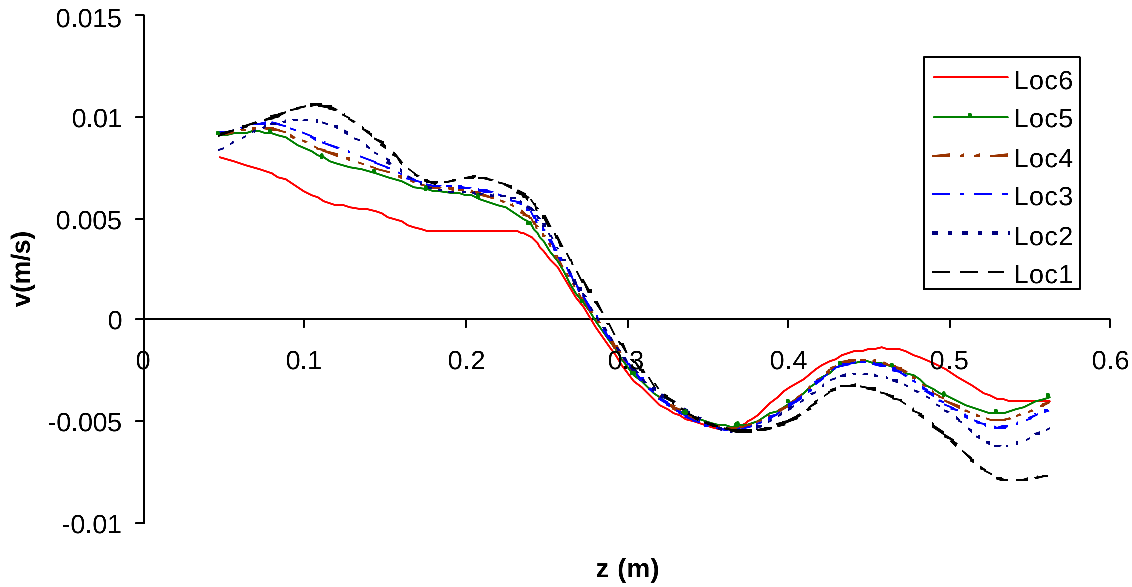

Figure 8 Case DUNE10 Spanwise velocity components along spanwise direction for all 6 locations – LSPIV results

CONCLUSIONS

The summary of some preliminary results of the ongoing studies on channel bed- surface velocity relationship is presented here. Based on the analysis the following conclusions can be drawn:

- For the given flow conditions, even though aspect ratios are smaller than the values seen in natural rivers, it is clearly seen that surface velocity reacts to spatial changes in channel bottom.
- The distribution of velocity component in spanwise direction is an indication to secondary motions in the flow.
- There might be a bias in calculated velocities by LSPIV resulted by the slip of seeding particles used. This general problem of all optically based measurement methods in which seed are used, needs further consideration.
- Consistency in the obtained data for these two flow cases is a validation of the measurement techniques used in a relative sense.

Present results show that further studies are required to define the effect of bathymetry quantitatively. It is hoped that new and useful results will be obtained by quantifying how well the seeding particles for LSPIV follow the flow; extending the range of concern of flow properties, like aspect ratio and free surface velocity for these channel bed configurations; extending the range of different channel bed characteristics and considering the other affects like, sidewalls and surface waviness on free surface. These results will be of high practical importance for the emerging generation of remote, non-contact discharge measurement technologies.

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